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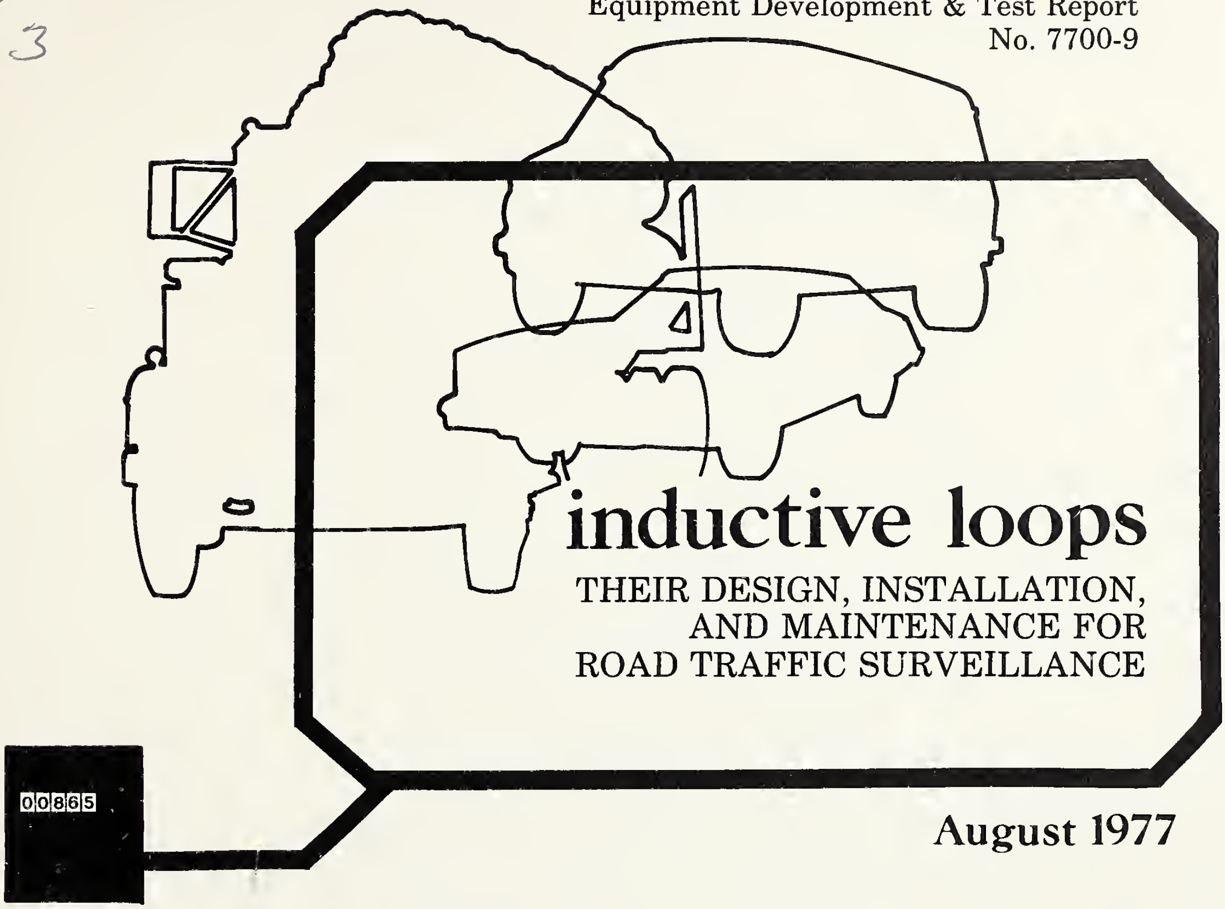

inductive loops

THEIR DESIGN, INSTALLATION, AND MAINTENANCE FOR ROAD TRAFFIC SURVEILLANCE

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Forest Service
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Inductive Loops – Their Design, Installation, and Maintenance for Road Traffic Surveillance

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Abstract

Inductive loop detectors are used to obtain road traffic data on National Forests. Loops consist of one or more turns of wire, usually arranged in a rectangle and buried in the road surface. The loop is connected by lead-in wires to a traffic detector that drives an alternating flow of current in the wire, producing a magnetic field. When a vehicle passes over the loop and through this magnetic field, eddy currents are induced, causing a drop in loop inductance. The detector senses this change and advances a recording mechanism, registering a count.

Effective inductance—the inductance presented to the terminals of a detector—should be in the 100 to 300 microhenry range for accurate traffic counting. Numbers 14 and 12 American Wire Gage stranded copper wire are good choices for loops. Polyvinylchloride insulation is adequate for short-term installations—3 to 5 years—at dry sites on gravel roads and where lead-in's can be 30 feet or less. Polyethylene-insulated wire is recommended for all other situations as it offers the maximum resistance to moisture and damage.

Several factors dictate loop design: the kinds of traffic to be counted; the need to limit lead-in inductance and capacitance; and the overall requirement that inductance presented to the detector should be in the 100 to 300 microhenry range.

Reference tables supply information to quickly determine a proper loop design. The steps required to install, inspect, and test loops are discussed.

Keywords: Traffic surveillance equipment, inductive loops, road traffic counters, road administration/planning, National Forest transportation policy, equipment engineering, equipment development, equipment testing.

A report written under Equipment Development and Test (ED&T) Project 2538, Inductive Loop Traffic Surveillance Equipment, for the Engineering Staff.

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Introduction

This report will help resolve the many uncertainties surrounding inductive loop design. It is a confusing situation at best for the fieldman seeking information to insure that his loop performs accurately and reliably with inductive loop detectors in road traffic counting installations. Where does he turn for facts? What wire should he use in constructing loops? What loop configurations are best?

The Equipment Development Center at Missoula has been investigating traffic surveillance equipment since 1970 under Equipment Development and Test Project 1983, Road Traffic Counters. After looking into various methods of counting traffic, the Center recommended that the Forest Service use inductive loop detectors[1] to obtain traffic data. Most of these detectors impose similar constraints on the sensing mechanism, the inductive loop.

To gain a sound theoretical understanding and mathematical description of inductive loops from which loop design criteria could be derived, the Missoula Center contracted with the electrical engineering department of Montana State University, Bozeman. That study was conducted by Professors N.A. Shyne and J.P. Hanton. They developed models of loops, derived equations to describe the models, and verified the accuracy of their models using experimental test data. The two researchers designed a computer program for calculating coil inductance, and Center engineers modified and extended the program to generate design data for this report.

In addition, literature from five manufacturers was reviewed in detail to gain perspective from the experience of these companies. Their installation manuals contained some errors, and disagreements were found with the choice of materials, construction, and operation of loops.

Based on our findings, we present here a description of inductive loops and how they work, materials used in constructing loops, and proper loop design. There are also sections about installation and maintenance procedures.

[1]A distinction can be made between counters and detectors. A counter is a device that both detects and counts traffic; detectors do not contain a counter, but must be used with a separate device that tallies traffic totals.

Theory of Loops

Inductive loops consist of one or more turns of wire, usually arranged in a rectangle. Inductive loops, as their name implies, operate by exploiting the electrical property of inductance. Inductance, measured in microhenries, can be defined as that property of an electric circuit whereby electromotive force is induced in a circuit by a change of current.

But how is this property applied to traffic detection? The loop is buried just below the surface of the roadway and connected to the terminals of a traffic detector by a pair of wires, called a lead-in. The traffic detector drives an alternating flow of current through the loop at or below resonant frequency. (Operating frequencies range from 20,000 to 120,000 cycles per second −20-120 kilohertz (kHz).) When a vehicle crosses the loop, eddy currents are induced causing an apparent drop in loop inductance. The detector senses this change and advances a recording mechanism to register a count.

Detectors monitor inductance in several ways. With *self-tuning detectors,* the oscillator is automatically adjusted to a null condition in feedback circuits. Any drop in inductance temporarily "detunes" the loop, causing a phase shift or amplitude change in the current flowing through the loop. Long-term inductance changes, such as a vehicle parked on part of the loop, are compensated for by the feedback circuit automatically tuning to a new null. Traffic Data Systems' LDC-353 and LDC-355 are two examples of self-tuning detectors.

In *manually tuned detectors,* such as Streeter Amet's 260 series, a tuned condition is achieved by adjusting the capacitance of the output circuit to match the loop to the detector's fixed frequency. No compensation is provided for long-term inductance changes.

A third type of detector, for example, Streeter Amet's Spadet Jr. or 703 series, uses a *balanced bridge* circuit. The loop is placed in one arm of the bridge. A vehicle-caused drop in inductance unbalances the bridge causing an output signal. The most critical problem is maintaining balance despite changes in lead-in capacitance, which varies with temperature and moisture. This is also a problem with manually tuned detectors. The balanced bridge detector does not compensate for long-term inductance changes.

Besides inductance and capacitance, loops and lead-ins exhibit the electrical property of resistance and the frequency-related properties of reactance, impedance, resonance, and "Q," the quality factor of the loop. Traffic detectors respond to the net effect of these properties or to changes in them.

However, our studies indicate that when designing a loop, it is sufficient to consider only *effective* inductance; that is, the inductance presented to the terminals of the detector. Effective inductance includes not only the inductance of the loop (or loops), but also the effects of inductance and capacitance of the lead-in. Most detectors operate with inductances ranging from 50 to 500 microhenries.[2] But based on our experience, effective inductance of the loop installation should be in the 100 to 300 microhenry range for accurate traffic counting. To achieve this, choice of wire is important, as well as the physical design of the loop itself.

[2]Manufacturers' literature should be carefully monitored. In some cases, inductance ranges change in a given model without being called to the user's attention.

Wire Selection

Loops

Wire size and insulation greatly affect loop performance—how well inductance change caused by a passing vehicle is presented to the detector.

A loop's ability to reflect an inductance change is increased with large wire sizes such as #14 or #12 American Wire Gage (AWG) because resistance is negligible. Wire can be solid or stranded aluminum or copper. Stranded copper is a good choice. It is easier to form into a loop, and copper is less resistive than aluminum.

Type TW (moisture resistant thermoplastic) or type THW (moisture and heat resistant thermoplastic) wire with polyvinyl chloride (PVC) insulation is adequate for both loop *and* lead-in under these conditions: short-term installations (3 to 5 years) at dry sites on gravel roads and where short lead-ins (30 feet or less) are possible. Because of the number of small pinholes in PVC insulation, the loop can be grounded out on long lead-ins where wet conditions exist.

A better choice for wet conditions is polyethylene (PE) insulation. Any insulation has pinhole flaws that allow conductive paths to form from the wire when the ground is moist. But PE insulation is manufactured by a process that involves thorough melting of the material, resulting in fewer pinholes than PVC.

Type USE (underground service entrance) or type UF (underground feeder) direct burial wire insulated with PE offers the maximum resistance to moisture and damage for loops (Type USE and UF can be purchased with PE-insulated conductors even though the outer jacket may be PVC.)

Where wire could contact hot tar or hot asphalt, as when roads are being resurfaced, type USE or UF wire with silicon rubber insulation may be a good compromise. It is not as mechanically durable as PE insulation but withstands temperatures to 300°F.

Lead-Ins

Large wire sizes—#14 and #12 AWG—should also be used for lead-ins. Specific types of wire and insulation depend on the site and lead-in length.

For short lead-ins at dry sites, type TW or THW wire with PVC insulation is adequate. Type USE and UF wire should not be used for lead-in wire since lead-ins must be twisted at least three turns per foot throughout their length. Twisting the wire together eliminates any small "loops," which can occur in the wire otherwise. Such "loops" increase lead-in inductance reducing the installation's ability to detect traffic.

Lead-in inductance must be kept small because a passing vehicle rarely reduces loop inductance more than 1 or 2 percent. (The exact percentage depends on how nearly the vehicle fills the loop.) By adding a large lead-in inductance, the vehicle-caused drop in loop inductance becomes proportionately even smaller. When large lead-in inductances "dilute" vehicle-caused reductions in this way, the detector cannot always "sense" the change, and counting accuracy declines.

Capacitance is an important concern in wire selection, particularly when choosing a wire for long lead-ins, since it, too, has the effect of boosting lead-in inductance. The capacitance of wire is rated in picofarads per foot (pF/ft). Wire for lead-ins should be rated at 25 pF/ft or less at 70°F. Capacitance varies with temperature and moisture, so a good insulation can minimize these effects.

For long lead-ins we recommend wire insulated with crosslinked[3] PE instead of PVC to limit capacitance. The capacitance of PVC and PE are about the same at 70°F. But for each 10 degrees of temperature change, the capacitance of PVC changes about 5 percent, that of PE less than 0.1 percent. Since self-tuning detectors must track that change, and manually tuned detectors may require retuning, it is best to limit capacitance changes by choosing wire insulated with PE.

PE-insulated cables suitable for long lead-ins are Belden's part numbers 8720 (#14 AWG) and 8718 (#12 AWG) or equivalent. These cables consist of a twisted, shielded pair of stranded, tinned copper conductors in a vinyl outer jacket. Belden also markets a good high density insulated #12 AWG stranded wire (part number YR-14903) for loops and short lead-ins.

[3]Crosslinking is a means of modifying the base structure of PE. This can be accomplished either by irradiation with high energy electron beams or through chemical crosslinking additives. Crosslinking increases continuous-use temperature, an important requirement in cable insulation.

Loop Design

The guidelines in this section are for designing loops that are as compatible as possible with available detectors. The object of good design is to fashion a loop that easily presents inductance change to the detector. The ability to reflect changed inductance is called *sensitivity* and is defined as the change in effective inductance occurring when a vehicle crosses the loop. The designer should also know how small an inductance change his detector will pick up. Manufacturers or the Missoula Center can supply that information.

Several factors dictate loop design: the kinds of traffic you want to count; the need to limit lead-in inductance and capacitance; and the overall requirement that inductance presented to the detector—effective inductance—should be in the 100 to 300 microhenry range.

Small loops extending no more than 6 to 10 feet down the roadway do an accurate job of detecting motorcycles, snowmobiles, and cars, but often logging trucks are counted as two vehicles (the trailer often causes a separate count). If logging trucks must be counted as single units, for maintenance sharing data, for example, the loop should extend 12 to 14 feet or more down the roadway; 6 to 10 feet is ample if your detector has a time delay, however.[4] Loops extending 12 to 14 feet down the road are accurate for cars and most trucks. These larger loops perform well with car and truck traffic but may miss most motorcycles.

In general, loops on forest roads should extend to within 3 feet of the shoulder, so vehicles cannot bypass the loop. Avoid shoulders and ditches where road maintenance equipment could damage loop or lead-in wires.

[4]The time delay is a popular detector modification. When loaded logging trucks must be counted as one unit of traffic, a time delay is incorporated so the detector does not reset to the original "ready" condition for 0.5 to 1 second after inductance has returned to normal.

With two or more loops and some logic circuitry, individual lane-counting or direction-of-flow data can be obtained. The primary difficulty is that the loops can interfere with each other, a problem that relates closely to the detector used. For such multiloop installations, you may want to contact the Missoula Center for technical help.

Once you have decided on the classes of traffic to be counted, you can choose the best combination of dimensions and number of turns for your loop. To verify that your choice is a good one—within the 100 to 300 microhenry range—calculate the effective inductance of your loop installation.

Four steps are involved:

- Refer to table 1 to find the inductance of your loop.[5]
- Calculate lead-in inductance.
- Calculate lead-in capacitance.
- Refer to table 2, 3, or 4—depending on your detector frequency—for effective inductance.

[5]To compute the inductance of two or more loops connected in series, add the inductance of each loop together. For loops connected in parallel, inductances cannot simply be added because parallel loops combine to produce a total loop inductance smaller than the inductance of individual loops; mathematically this is expressed

$$\frac{1}{\text{total loop inductance}} = \frac{1}{L_1} + \frac{1}{L_2}$$

where L_1 is the inductance of one loop and L_2 the inductance of the second. Loops connected in series or in parallel do not improve traffic counting ability and require more time and effort to install, so it is best to avoid them. However, they can be employed to "save" a loop installation where effective inductance is either too high or too low. If too high, a loop connected in parallel to the malfunctioning loop can reduce inductance to the proper microhenry range; if too low, a loop connected in series may raise effective inductance to that range.

Table 1.—*Inductance vs. loop size and number of turns*

Length (Feet)	Width (Feet)	Inductance in Microhenries: 1 Turn	2 Turns	3 Turns	4 Turns	5 Turns
2	2	3	10	21	34	51
2	4	5	16	33	55	81
2	6	6	22	45	75	112
2	8	8	28	57	95	142
4	4	7	23	47	79	118
4	6	9	29	61	103	153
4	8	10	36	75	126	188
4	10	12	43	89	149	223
4	12	14	49	102	172	257
4	14	16	56	116	195	292
4	16	18	62	129	218	326
6	6	11	37	76	129	192
6	8	13	44	91	154	230
6	10	14	51	106	178	267
6	12	16	58	120	203	305
6	14	18	65	135	228	342
6	16	20	71	149	252	379
6	18	22	78	164	277	416
6	20	24	85	178	301	452
6	22	26	92	193	326	489
6	24	28	99	207	350	526
8	8	15	51	107	180	270
8	10	17	58	122	207	310
8	12	19	66	138	233	349
8	14	21	73	153	259	388
8	16	23	80	168	284	427
8	18	25	87	183	310	466
8	20	27	95	198	336	505
8	22	29	102	214	362	543
8	24	31	109	229	387	582
8	26	33	116	244	413	621
8	28	35	123	259	438	659
8	30	37	130	274	464	698
8	32	39	138	289	490	737
10	10	19	66	138	234	351
10	12	21	74	154	261	392
10	14	23	81	170	288	433
10	16	25	89	186	315	474
10	18	27	96	202	342	514
10	20	29	103	218	368	554
10	22	31	111	233	395	594
10	24	33	118	249	422	635
10	26	35	126	264	448	675
10	28	38	133	280	475	715
10	30	40	140	296	501	755
10	32	42	148	311	528	795
10	34	44	155	327	554	835
10	36	46	163	342	581	875
10	38	48	170	358	607	915
10	40	50	177	374	634	955
12	12	23	81	171	289	435
12	14	25	89	187	317	477
12	16	27	97	204	345	519
12	18	30	104	220	373	561
12	20	32	112	236	400	602
12	22	34	120	252	428	644
12	24	36	127	268	455	685
12	26	38	135	284	482	726
12	28	40	143	300	510	768
12	30	42	150	316	537	809
12	32	44	158	332	564	850
12	34	47	165	348	591	891
12	36	49	173	364	619	932
12	38	51	180	380	646	973
12	40	53	188	396	673	1015
14	14	27	97	204	346	521
14	16	30	105	221	375	564
14	18	32	113	238	403	607
14	20	34	121	254	431	649
14	22	36	128	271	459	692
14	24	38	136	287	487	734
14	26	41	144	304	515	777
14	28	43	152	320	543	819
14	30	45	159	336	571	861
14	32	47	167	353	599	903
14	34	49	175	369	627	946
14	36	51	183	386	655	988
14	38	53	190	402	683	1030
14	40	56	198	418	711	1072
16	16	32	113	238	404	608
16	18	34	121	255	433	652
16	20	36	129	272	462	696
16	22	39	137	289	491	739
16	24	41	145	306	519	783
16	26	43	153	323	548	826
16	28	45	161	339	576	869
16	30	47	169	356	605	912
16	32	50	177	373	634	955
16	34	52	184	389	662	999
16	36	54	192	406	690	1042
16	38	56	200	423	719	1085
16	40	58	208	439	747	1128
18	18	36	129	272	463	697
18	20	39	137	290	492	742
18	22	41	145	307	521	786
18	24	43	154	324	551	830
18	26	45	162	341	580	875
18	28	48	170	358	609	919
18	30	50	178	375	638	963
18	32	52	186	392	667	1007
18	34	54	194	409	696	1050
18	36	57	202	426	725	1094
18	38	59	210	443	754	1138
18	40	61	218	460	783	1182
20	20	41	146	307	522	787
20	22	43	154	325	552	833
20	24	46	162	342	582	878
20	26	48	170	360	612	923
20	28	50	178	377	641	968
20	30	52	187	394	671	1012
20	32	55	195	412	700	1057
20	34	57	203	429	730	1102
20	36	59	211	446	759	1146
20	38	61	219	463	789	1191
20	40	64	227	481	818	1235
22	22	46	162	343	583	879
22	24	48	171	360	613	925
22	26	50	179	378	643	970
22	28	52	187	396	673	1016
22	30	55	195	413	703	1061
22	32	57	204	431	733	1107
22	34	59	212	448	763	1152
22	36	62	220	466	793	1197
22	38	64	228	483	823	1243
22	40	66	237	501	853	1288
24	24	50	179	378	644	971
24	26	53	187	396	674	1018
24	28	55	196	414	705	1064
24	30	57	204	432	735	1110
24	32	59	213	450	766	1156
24	34	62	221	468	796	1202
24	36	64	229	485	826	1248
24	38	66	238	503	857	1294
24	40	69	246	521	887	1340
26	26	55	196	415	705	1065
26	28	57	205	433	736	1112
26	30	60	213	451	767	1159
26	32	62	221	469	798	1205
26	34	64	230	487	829	1252
26	36	67	238	505	859	1298
26	38	69	247	522	890	1345
26	40	71	255	540	921	1391
28	28	60	213	451	768	1159
28	30	62	222	469	799	1207
28	32	64	230	487	830	1254
28	34	67	239	506	861	1301
28	36	69	247	524	892	1348
28	38	71	256	542	923	1395
28	40	74	264	560	954	1442
30	30	64	230	488	831	1255
30	32	67	239	506	862	1303
30	34	69	248	525	894	1350
30	36	72	256	543	925	1398
30	38	74	265	561	956	1445
30	40	76	273	579	988	1493
32	32	69	248	525	894	1351
32	34	72	256	543	926	1399
32	36	74	265	562	958	1447
32	38	76	274	580	989	1495
32	40	79	282	599	1021	1543
34	34	74	265	562	958	1448
34	36	76	274	581	990	1497
34	38	79	283	599	1022	1545
34	40	81	291	618	1054	1594
36	36	79	283	600	1022	1546
36	38	81	292	619	1055	1595
36	40	84	300	637	1087	1644
38	38	84	301	638	1087	1644
38	40	86	309	656	1120	1694
40	40	89	318	676	1152	1743

Table 2.—*Effective inductance for 50 kHz detectors (in microhenries)*

TOTAL LEAD–IN CAPACITANCE (IN PICOFARADS)	LOOP PLUS LEAD–IN INDUCTANCE (IN MICROHENRIES) 50	100	150	200	250	300	350	400	450	500
	50	100	150	200	250	300	350	400	450	500
100	50	100	150	200	251	301	351	402	452	502
200	50	100	150	201	251	302	352	403	454	505
300	50	100	151	201	252	303	354	405	456	508
400	50	100	151	202	252	304	355	406	458	510
500	50	100	151	202	253	305	356	408	460	513
600	50	101	151	202	254	305	357	410	462	515
700	50	101	152	203	254	306	359	411	464	518
800	50	101	152	203	255	307	360	413	467	521
900	50	101	152	204	256	308	361	415	469	523
1000	50	101	152	204	256	309	363	416	471	526
1100	50	101	152	204	257	310	364	418	473	529
1200	50	101	153	205	258	311	365	420	475	531
1300	50	101	153	205	258	312	366	422	478	534
1400	50	101	153	206	259	313	368	423	480	537
1500	50	102	153	206	260	314	369	425	482	540
1600	50	102	154	207	260	315	370	427	484	543
1700	50	102	154	207	261	316	372	429	487	546
1800	50	102	154	207	262	317	373	431	489	549
1900	50	102	154	208	262	318	375	432	491	552
2000	50	102	155	208	263	319	376	434	494	555
2100	51	102	155	209	264	320	377	436	496	558
2200	51	102	155	209	264	321	379	438	499	561
2300	51	102	155	210	265	322	380	440	501	564
2400	51	102	156	210	266	323	382	442	504	567
2500	51	103	156	210	266	324	383	444	506	570
2600	51	103	156	211	267	325	385	446	509	574
2700	51	103	156	211	268	326	386	448	511	577
2800	51	103	156	212	269	327	387	450	514	580
2900	51	103	157	212	269	328	389	452	517	584
3000	51	103	157	213	270	329	390	454	519	587
3100	51	103	157	213	271	330	392	456	522	590
3200	51	103	157	213	271	331	393	458	525	594
3300	51	103	158	214	272	332	395	460	527	597
3400	51	103	158	214	273	334	397	462	530	
3500	51	104	158	215	274	335	398	464	533	
3600	51	104	158	215	274	336	400	466	536	
3700	51	104	159	216	275	337	401	468	538	
3800	51	104	159	216	276	338	403	471	541	
3900	51	104	159	217	277	339	404	473	544	
4000	51	104	159	217	277	340	406	475	547	
4100	51	104	160	218	278	341	408	477	550	
4200	51	104	160	218	279	343	409	480	553	
4300	51	104	160	219	280	344	411	482	556	
4400	51	105	160	219	280	345	413	484	559	
4500	51	105	161	219	281	346	414	486	562	
4600	51	105	161	220	282	347	416	489	566	
4700	51	105	161	220	283	348	418	491	569	
4800	51	105	161	221	284	350	420	494	572	
4900	51	105	162	221	284	351	421	496	575	
5000	51	105	162	222	285	352	423	498	578	
5100	51	105	162	222	286	353	425	501	582	
5200	51	105	163	223	287	355	427	503	585	
5300	51	106	163	223	288	356	428	506	589	
5400	51	106	163	224	288	357	430	508	592	
5500	51	106	163	224	289	358	432	511	595	
5600	51	106	164	225	290	360	434	514	599	
5700	51	106	164	225	291	361	436	516		
5800	51	106	164	226	292	362	438	519		
5900	51	106	164	226	293	364	440	521		

TOTAL LEAD–IN CAPACITANCE (IN PICOFARADS)	LOOP PLUS LEAD–IN INDUCTANCE (IN MICROHENRIES) 50	100	150	200	250	300	350	400
6000	52	106	165	227	293	365	442	524
6100	52	106	165	227	294	366	443	527
6200	52	107	165	228	295	367	445	530
6300	52	107	165	228	296	369	447	532
6400	52	107	166	229	297	370	449	535
6500	52	107	166	229	298	371	451	538
6600	52	107	166	230	299	373	453	541
6700	52	107	167	230	300	374	455	544
6800	52	107	167	231	300	376	457	547
6900	52	107	167	232	301	377	460	550
7000	52	107	167	232	302	378	462	553
7100	52	108	168	233	303	380	464	556
7200	52	108	168	233	304	381	466	559
7300	52	108	168	234	305	383	468	562
7400	52	108	168	234	306	384	470	565
7500	52	108	169	235	307	386	472	568
7600	52	108	169	235	308	387	475	571
7700	52	108	169	236	309	389	477	575
7800	52	108	170	236	310	390	479	578
7900	52	108	170	237	311	392	481	581
8000	52	109	170	238	311	393	484	585
8100	52	109	170	238	312	395	486	588
8200	52	109	171	239	313	396	488	591
8300	52	109	171	239	314	398	491	595
8400	52	109	171	240	315	399	493	598
8500	52	109	172	240	316	401	495	
8600	52	109	172	241	317	402	498	
8700	52	109	172	241	318	404	500	
8800	52	110	172	242	319	406	503	
8900	52	110	173	243	320	407	505	
9000	52	110	173	243	321	409	508	
9100	52	110	173	244	322	411	510	
9200	52	110	174	244	323	412	513	
9300	52	110	174	245	324	414	516	
9400	52	110	174	246	325	416	518	
9500	52	110	175	246	327	417	521	
9600	52	110	175	247	328	419	524	
9700	53	111	175	247	329	421	526	
9800	53	111	176	248	330	423	529	
9900	53	111	176	249	331	424	532	
10000	53	111	176	249	332	426	535	
10500	53	112	178	252	337	435	549	
11000	53	112	179	255	340	445	564	
11500	53	113	181	257	[illegible]	[illegible]	581	
12000	53	113	182	262	[illegible]	[illegible]	599	
12500	53	114	184	266	361	[illegible]		
13000	53	115	186	269	366	[illegible]		
13500	54	115	187	[illegible]	371	[illegible]		
14000	54	116	189	[illegible]	382	[illegible]		
14500	54	117	191	280	389	526		
15000	54	117	193	284	397	540		
15500	54	[illegible]	195	288	405	554		
16000	54	[illegible]	197	292	413	570		
16500	54	119	198	297	422	587		
17000	55	120	200	301	431			
17500	55	121	202	[illegible]	[illegible]			
18000	55	122	204	[illegible]	[illegible]			
18500	55	122	207	[illegible]	460			
19000	55	[illegible]	209	[illegible]	471			
19500	[illegible]	[illegible]	211	[illegible]	[illegible]			
20000	[illegible]	125	[illegible]	[illegible]	[illegible]			

Table 3.—*Effective inductance for 75 kHz detectors (in microhenries)*

TOTAL LEAD–IN CAPACITANCE (IN PICOFARADS)	LOOP PLUS LEAD–IN INDUCTANCE (IN MICROHENRIES)									
	50	100	150	200	250	300	350	400	450	500
-	50	100	150	200	250	300	350	400	450	500
100	50	100	151	201	251	302	353	404	455	506
200	50	100	151	202	253	304	356	407	459	511
300	50	101	152	203	254	306	358	411	464	517
400	50	101	152	204	256	308	361	415	469	523
500	50	101	153	205	257	310	364	419	474	529
600	50	101	153	205	259	312	367	423	479	536
700	50	102	154	206	260	315	370	427	484	542
800	50	102	154	207	262	317	373	431	489	549
900	51	102	155	208	263	319	376	435	494	556
1000	51	102	155	209	265	321	379	439	500	562
1100	51	103	156	210	266	324	383	443	506	570
1200	51	103	156	211	268	326	386	448	511	577
1300	51	103	157	212	269	328	389	452	517	584
1400	51	103	157	213	271	331	393	457	523	592
1500	51	103	158	214	273	333	396	461	529	600
1600	51	104	158	215	274	336	400	466	536	
1700	51	104	159	216	276	338	403	471	542	
1800	51	104	160	217	278	341	407	476	549	
1900	51	104	160	218	279	343	411	481	555	
2000	51	105	161	219	281	346	414	486	562	
2100	51	105	161	221	283	349	418	492	570	
2200	51	105	162	222	285	352	422	497	577	
2300	51	105	162	223	287	354	426	503	584	
2400	51	106	163	224	288	357	430	508	592	
2500	51	106	164	225	290	360	434	514	600	
2600	51	106	164	226	292	363	439	520		
2700	52	106	165	227	294	366	443	526		
2800	52	107	165	228	296	369	447	532		
2900	52	107	166	230	298	372	452	539		
3000	52	107	167	231	300	375	456	545		
3100	52	107	167	232	302	378	461	552		
3200	52	108	168	233	304	381	466	559		
3300	52	108	169	234	306	385	471	566		
3400	52	108	169	236	308	388	476	573		
3500	52	108	170	237	310	391	481	580		
3600	52	109	170	238	312	395	486	588		
3700	52	109	171	239	315	398	491	596		
3800	52	109	172	241	317	402	497			
3900	52	109	172	242	319	405	502			
4000	52	110	173	243	321	409	508			
4100	52	110	174	245	324	413	514			
4200	52	110	174	246	326	417	520			
4300	53	111	175	247	328	420	526			
4400	53	111	176	249	331	424	532			
4500	53	111	176	250	333	428	538			
4600	53	111	177	251	336	433	545			
4700	53	112	178	253	339	437	551			
4800	53	112	179	254	341	441	558			
4900	53	112	179	256	343	445	565			
5000	53	112	180	257	346	450	572			
5100	53	113	181	259	349	454	580			
5200	53	113	181	260	351	459	587			
5300	53	113	182	262	354	464	595			
5400	53	114	183	263	357	469				
5500	53	114	184	265	360	473				
5600	53	114	184	266	363	479				
5700	53	114	185	268	366	484				
5800	53	115	186	269	369	489				
5900	54	115	187	271	372	494				
6000	54	115	187	273	375	500				

TOTAL LEAD–IN CAPACITANCE (IN PICOFARADS)	LOOP PLUS LEAD–IN INDUCTANCE (IN MICROHENRIES)					
	50	100	150	200	250	300
6100	54	116	188	274	378	505
6200	54	116	189	276	381	511
6300	54	116	190	278	384	517
6400	54	117	191	279	388	523
6500	54	117	191	281	391	529
6600	54	117	192	283	395	535
6700	54	117	193	285	398	542
6800	54	118	194	287	402	548
6900	54	118	195	288	405	555
7000	54	118	196	290	409	562
7100	54	119	196	292	413	569
7200	54	119	197	294	416	577
7300	54	119	198	296	420	584
7400	54	120	199	298	424	592
7500	55	120	200	300	428	600
7600	55	120	201	302	432	
7700	55	121	202	304	437	
7800	55	121	203	306	441	
7900	55	121	204	308	445	
8000	55	122	204	310	450	
8100	55	122	205	312	454	
8200	55	122	206	315	459	
8300	55	123	207	317	464	
8400	55	123	208	319	468	
8500	55	123	209	321	473	
8600	55	124	210	324	478	
8700	55	124	211	326	484	
8800	55	124	212	328	489	
8900	55	125	213	331	494	
9000	56	125	214	333	500	
9100	56	125	215	336	505	
9200	56	126	216	338	511	
9300	56	126	217	341	517	
9400	56	126	218	343	523	
9500	56	127	219	346	529	
9600	56	127	221	349	535	
9700	56	127	222	351	542	
9800	56	128	223	354	548	
9900	56	128	224	357	555	
10000	56	129	225	360	562	
10500	57	130	231	375	599	
11000	57	132	237	391		
11500	57	134	243	409		
12000	58	136	250	428		
12500	58	138	257	450		
13000	58	141	265	475		
13500	59	143	273	499		
14000	59	145	281	529		
14500	60	147	290	562		
15000	60	150	300	599		
15500	60	152	310			
16000	61	155	321			
16500	61	158	333			
17000	62	161	346			
17500	62	164	360			
18000	62	167	375			
18500	63	170	391			
19000	63	173	409			
19500	64	176	428			
20000	64	180	449			

Table 4—*Effective inductance for 100 kHz detectors (in microhenries)*

TOTAL LEAD–IN CAPACITANCE (IN PICOFARADS)	LOOP PLUS LEAD–IN INDUCTANCE (IN MICROHENRIES)									
	50	100	150	200	250	300	350	400	450	500
0	50	100	150	200	250	300	350	400	450	500
100	50	100	151	202	252	304	355	406	458	510
200	50	101	152	203	255	307	360	413	467	521
300	50	101	153	205	258	311	365	420	475	531
400	50	102	154	207	260	315	370	427	484	543
500	50	102	155	208	263	319	376	434	494	555
600	51	102	156	210	266	323	382	442	504	567
700	51	103	156	212	269	327	387	450	514	580
800	51	103	157	213	271	331	393	458	525	594
900	51	104	158	215	274	336	400	466	536	
1000	51	104	159	217	277	340	406	475	547	
1100	51	105	160	219	280	345	413	484	559	
1200	51	105	161	221	284	350	420	494	572	
1300	51	105	163	223	287	355	427	503	585	
1400	51	106	164	225	290	360	434	514	599	
1500	52	106	165	227	293	365	442	524		
1600	52	107	166	229	297	370	449	535		
1700	52	107	167	231	300	376	457	547		
1800	52	108	168	233	304	381	466	559		
1900	52	108	169	235	308	387	475	571		
2000	52	109	170	238	311	393	484	585		
2100	52	109	171	240	315	399	493	598		
2200	52	110	172	242	319	406	503			
2300	52	110	174	244	323	412	513			
2400	52	110	175	247	328	419	524			
2500	53	111	176	249	332	426	535			
2600	53	111	177	252	336	433	546			
2700	53	112	179	254	341	441	558			
2800	53	112	180	257	345	449	571			
2900	53	113	181	259	350	457	584			
3000	53	113	182	262	355	465	598			
3100	53	114	184	265	360	474				
3200	53	114	185	268	365	483				
3300	53	115	186	270	371	492				
3400	54	116	188	273	376	502				
3500	54	116	189	276	382	512				
3600	54	117	191	279	388	523				
3700	54	117	192	283	394	534				
3800	54	118	194	286	400	546				
3900	54	118	195	289	406	558				
4000	54	119	197	292	413	570				
4100	54	119	198	296	420	583				
4200	55	120	200	299	427	597				
4300	55	120	201	303	434					
4400	55	121	203	306	442					
4500	55	122	204	310	450					
4600	55	122	206	314	458					
4700	55	123	208	318	466					
4800	55	123	210	322	475					
4900	55	124	211	326	484					
5000	55	125	213	330	494					
5100	56	125	215	335	503					
5200	56	126	217	339	514					
5300	56	126	219	344	524					
5400	56	127	221	349	535					
5500	56	128	222	354	547					
5600	56	128	224	359	559					
5700	56	129	226	364	572					
5800	56	130	228	369	585					
5900	57	130	231	374	599					

TOTAL LEAD–IN CAPACITANCE (IN PICOFARADS)	LOOP PLUS LEAD–IN INDUCTANCE (IN MICROHENRIES)			
	50	100	150	200
6000	57	131	233	380
6100	57	132	235	386
6200	57	132	237	392
6300	57	133	239	398
6400	57	134	242	404
6500	57	135	244	411
6600	57	135	246	418
6700	58	136	249	425
6800	58	137	251	432
6900	58	137	254	439
7000	58	138	256	447
7100	58	139	259	455
7200	58	140	261	463
7300	58	140	264	472
7400	59	141	267	481
7500	59	142	270	490
7600	59	143	273	500
7700	59	144	276	510
7800	59	144	279	521
7900	59	145	282	532
8000	59	146	285	543
8100	60	147	288	555
8200	60	148	292	567
8300	60	149	295	580
8400	60	150	298	594
8500	60	151	302	
8600	60	151	306	
8700	60	152	309	
8800	61	153	313	
8900	61	154	317	
9000	61	155	321	
9100	61	156	325	
9200	61	157	330	
9300	61	158	334	
9400	61	159	338	
9500	62	160	343	
9600	62	161	348	
9700	62	162	352	
9800	62	163	357	
9900	62	164	363	
10000	62	165	368	
10500	63	171	397	
11000	64	177	430	
11500	65	183	470	
12000	66	190	518	
12500	66	197	577	
13000	67	205		
13500	68	214		
14000	69	224		
14500	70	234		
15000	71	245		
15500	72	258		
16000	73	271		
16500	74	287		
17000	75	304		
17500	76	323		
18000	78	346		
18500	79	371		
19000	80	400		
19500	81	434		
20000	83	475		

As an example, if you are interested in counting logging trucks, perhaps you would select a 10 x 14-foot loop. Checking table 1, which gives inductance figures for single loops with one to five turns, you might decide that a three-turn loop of 170 microhenries was appropriate.

Next calculate lead-in inductance. Multiply the length of your lead-in in feet times 0.22 microhenries (wire has a rating of 22 microhenries per 100 feet). A 125-foot lead-in, for example,would be 27.5 microhenries (125 x 0.22). Thus, loop plus lead-in inductance totals 197.5 microhenries (170 + 27.5).

Now calculate lead-in capacitance by multiplying the picofarads per foot rating of the lead-in wire times its length. A 125-foot lead-in of 25 pF/ft would be 3,125 picofarads.

Turn to table 2, 3, or 4, depending on the operating frequency of your detector, to determine the effective inductance of your design. For example, if your detector operates at 50 kHZ, turn to table 2. In the left-hand column of that table locate the lead-in capacitance figure closest to 3,125 picofarads, 3,100; next, under the loop plus lead-in inductance heading, locate the 200-microhenry column, the one closest to 197.2 microhenries. Moving across the table you find the effective inductance of your sample installation is 213 microhenries — within the range for a well-designed loop. (Actual effective inductance would be just below 213 since loop plus lead-in inductance was slightly less than 200 microhenries.)

When designing loops, these general guidelines may be helpful:

- As a rule, only 20 percent of a loop installation's inductance should be in the lead-in. Loop inductance can be raised by designing loops with multiple turns, limiting lead-in length, or both.[6]

- Lead-ins over 30 feet should be treated as long lead-ins and appropriate wire used.

- Lead-ins must never exceed 750 feet in length.

- Wire considered for lead-in should have a capacitance rating of 25 pF/ft or less at 70°F.

- For most long lead-ins, capacitance should not be allowed to vary more than 0.1 percent for every 10 degrees of temperature change. In other words, PE-insulated wire should be used in most cases.

- Consult wire manufacturers or the Missoula Center when considering new or unique wire insulation.

[6]Some loop designers have said they can facilitate tuning when effective inductance is low by adding a capacitor across lead-in wires. It increases effective inductance, but the contribution of capacitance makes it difficult for the detector to pick up the vehicle-caused change in inductance.

Installation

Installation consists of physically putting the loop in the roadway, splicing loop and lead-in if separate lead-in wire is used, and connecting lead-ins to a detector.

It is good practice to install loops that will last for the life of the road. In too many cases a loop is installed with a weak link such as a poor splice, and the loop functions properly for only a year or two. Much time and money go into a loop installation, so it should be done with care.

Select a site where traffic flows uniformly at moderate speed, and passing or parking is unlikely. Avoid areas close to intersections. Put the detector near the loop but out of view of traffic if possible.

Loops should be installed away from masses of metal such as reinforcing bar in concrete roadways and steel in bridge decks. Large amounts of metal make the loop less sensitive by reducing inductance by as much as 5 to 1.

Loop sensitivity is inversely proportional to the square of the distance from the loop to the vehicle, so loops should be as close to the surface of the roadway as possible and still maintain good physical and electrical properties.

When installing a loop in concrete or asphalt, draw an outline of the loop on the road surface. Avoid crossing expansion joints, and never use them as readymade slots. Use a diamond or abrasive saw blade 3/16-inch wide to cut a slot up to 1 inch deep in concrete or 2 to 3 inches deep in asphalt. Cut diagonals at the corners to eliminate sharp bends (fig.1). In gravel the loop should be 6 to 8 inches below the surface. Slots or trenches can be dug by hand with shovels and picks or with backhoes or roadgraders.

Figure 2 shows another method for forming loops that has a number of advantages for installations on gravel roads. Make a single loop with a length of three-conductor, UF cable with or without ground (ground wire is never used for loop). By splicing as shown in figure 2, a three-turn loop is created to which the lead-in is attached. The cable's outer jacket holds the conductors together offering greater resistance to moisture and damage. Lead-ins are then buried.

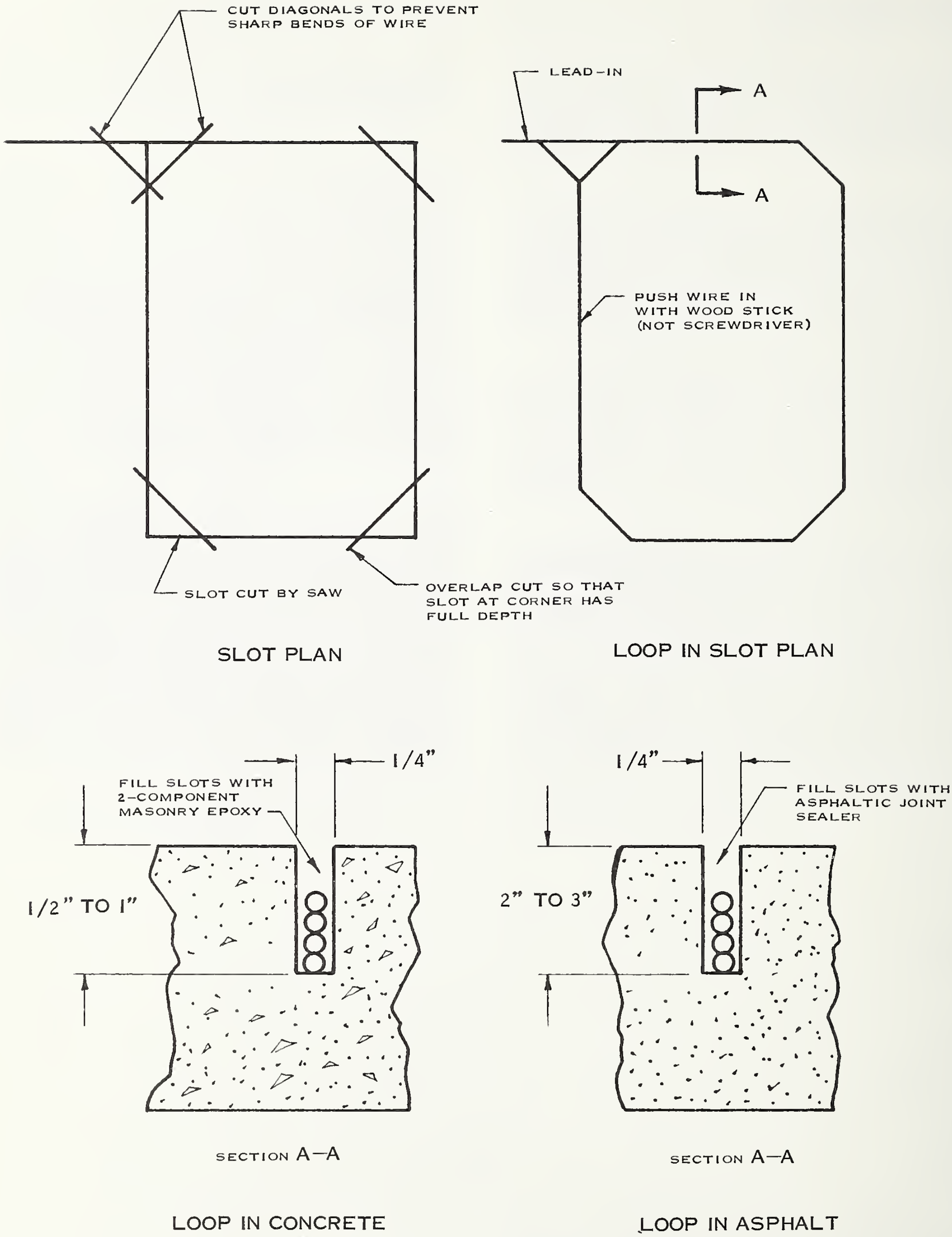


Figure 1.–Loop installation details.

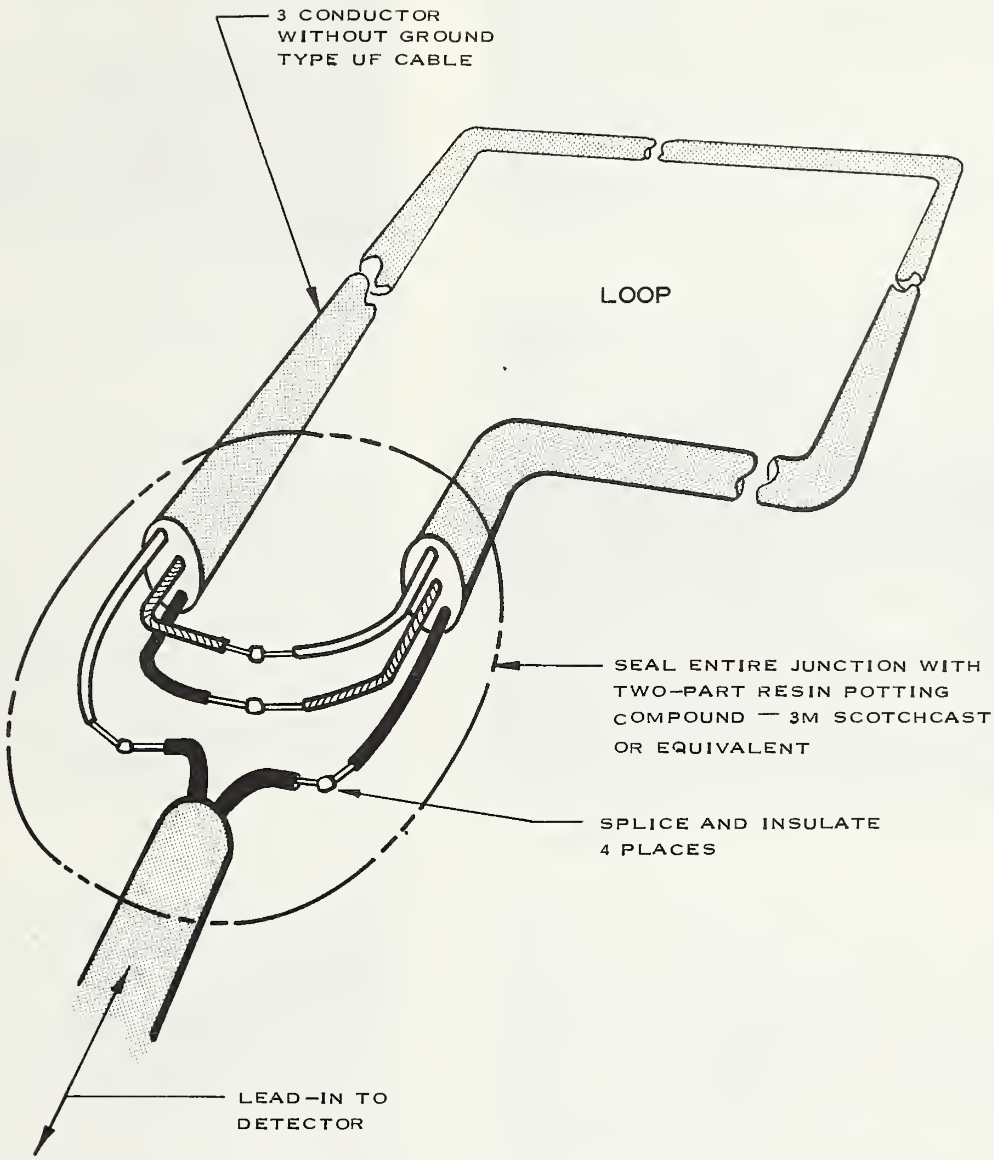


Figure 2.–Alternate method for loop fabrication on gravel roads.

At sites where lead-ins can be short, run a length of wire from the detector to the loop, form a loop of the required number of turns with the wire and continue it back to the detector. (On gravel, loops can be prefabricated and then placed on the road surface.) Position each turn in the slot, being careful not to damage wire insulation. A wooden tool can be used to position the wire in concrete or asphalt slots. Fill the slot with masonry epoxy (concrete roadway) or rubberized asphaltic joint sealer (asphalt road) (fig. 3). For gravel, secure the corners of the loop to stakes or nails driven well into the roadbed and cover with gravel. Keep wires together by taping every 3 to 5 feet. On roads to be resurfaced, simply tape the loop to the old surface (fig. 4). Make sure wire insulation can withstand the heat involved in applying a new road surface such as asphalt.

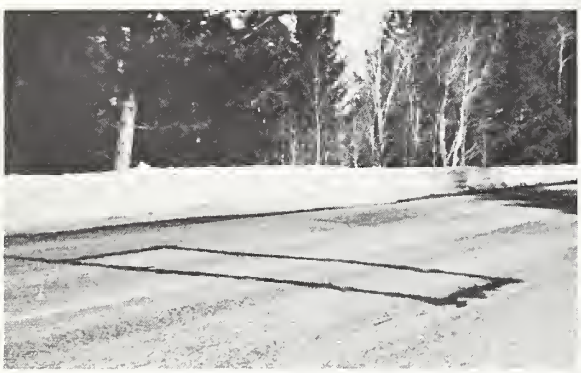


Figure 3—Loop installed on asphalt road.

Twist the lead-in wires together at least three turns per foot. This will insure that no small loops have been set up in the lead-in, which might increase inductance and reduce sensitivity. Route the lead-in in a shallow trench directly to the detector. Bury the lead-in several inches deeper than the loop for added protection against road maintenance equipment. Installing this section in rubber or plastic tubing or nonmetallic conduit also helps.

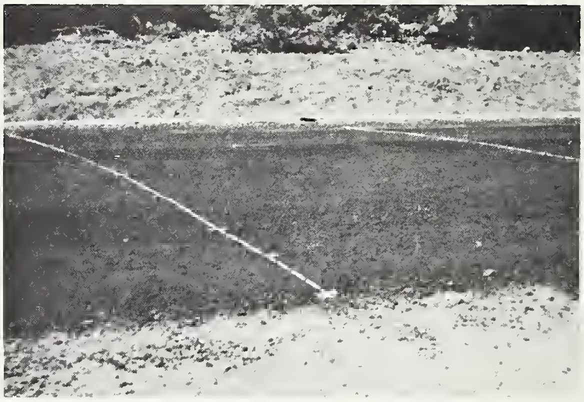
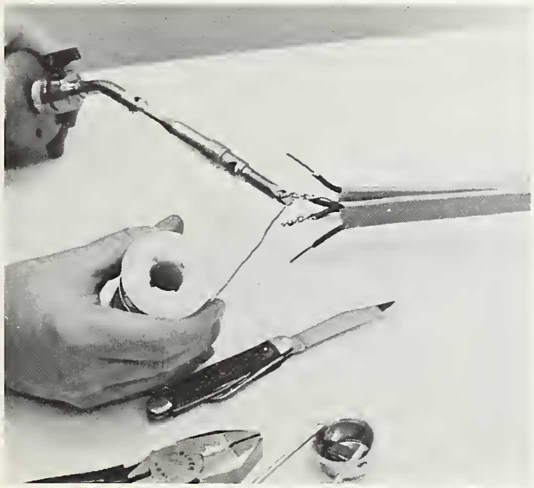


Figure 4—Loop taped to road surface.

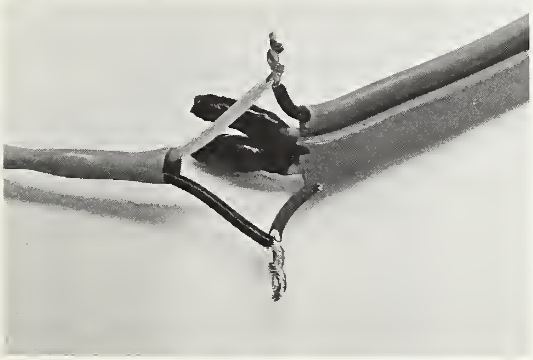
At sites requiring longer lead-ins, special lead-in wire is needed to keep the effects of capacitance within tolerable limits. PE-insulated cable such as Belden numbers 8720 or 8718 or equivalent are good choices.

Form the loop as above beginning and ending the loop at the roadway's edge. Then trim insulation from the ends of the loop wires. Some wire has an aluminum shield. This must be stripped from the ends of the wire and not used or connected in any way. Twist and solder individual wires (fig. 5, A and B). All soldering should be done with a 60/40 resin core solder. Never use acid flux solders. Tape the two ends of the unused conductor so they will not come in contact with the active conductor. Bind with rubber splicing compound and plastic tape. Now make the loop-to-lead-in splices by twisting together wires and soldering (fig. 5, C and D). Rubber splicing compound and plastic tape thoroughly seal area against moisture (fig. 5, E and F).

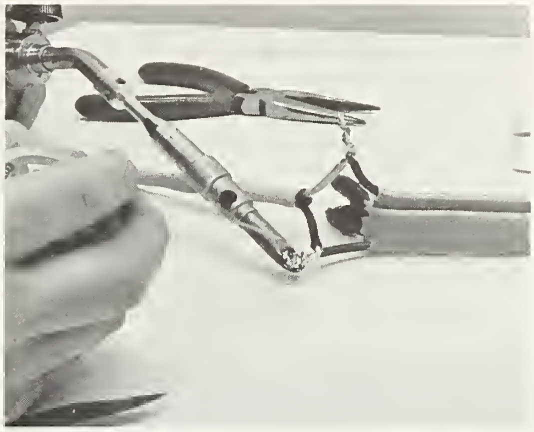
A.— Twist individual wires (three conductor cable is being used for loop).



B.— Solder each junction.



C.— Twist loop and lead-in wires together.



D.— Solder wires together.

E.— Wrap with rubber splicing compound and plastic tape.

F.— Properly taped splice.

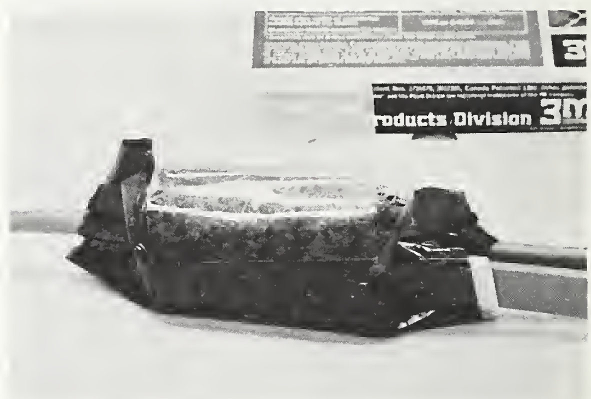
Figure 5.—Making loop-to-lead-in splice.

For permanent installations, we suggest two-part resin potting compounds such as 3M Co.'s Scotchcast or equivalent to seal splices (fig. 6). First, remove liners from sealing putty on mold body and position around splice (fig. 6, A and B). Compress sealing putty tightly around each cable. Pour resin into the mold and seal top (fig. 6, C and D). Resin hardens completely in about 30 minutes (fig. 6, E).

A.— Remove liners from sealing putty on mold.

B.— Position mold around splice.

C.— Pour resin into mold.



D.— Seal top of mold.

E.— Finished splice.

Figure 6.—Sealing loop-to-lead-in splice.

Inspection and Testing

Follow these steps when inspecting sites:

1. Determine if the loop may have been damaged by road maintenance equipment, shifts of pavement, or vandalism. Inspect the exposed end of the lead-in for evidence of deterioration.

2. Disconnect the lead-in from the detector and connect lead-in wires to an ohmmeter. Set the ohmmeter to its lowest range and measure the resistance of the loop and lead-in. Compare the indication with the design value. Refer to table 5 for resistivities.

Here is an example: A 12 x 20-foot, three turn loop constructed from #12 AWG copper wire with 150 feet of Belden 8720 lead-in. The total length of the loop is 192 feet (12 + 20) (2) (3). The 150-foot lead-in is #14 AWG copper wire with a total circuit length of 300 feet (2 x 150 feet). Since the resistance of #12 AWG is 1.588 ohms per 1,000 feet, and the resistance of #14 AWG is 2.525 ohms per 1,000 feet (table 5), loop resistance should be

$$\frac{192}{1{,}000} \times 1.588 = 0.305 \text{ ohms}$$

and the resistance of the lead-in should be

$$\frac{300}{1{,}000} \times 2.525 = 0.758 \text{ ohms},$$

totaling 1.06.

Resistances greater than the design value indicate faulty splices or partially severed conductors. Very high or infinite readings on the highest scale indicate an open circuit. In either case, repair or replacement is necessary.

3. With the lead-in disconnected from the detector, drive a metal stake well into the earth and measure the resistance between either conductor of the lead-in and ground. This is a test of the insulation. The metal stake must be driven deep enough to contact moist earth, and the highest range of the ohmmeter must be used. Resistance lower than 1 million ohms (1

Table 5.—*Resistivities for bare copper wire*

Gage (AWG)	*Diameter, (in), Nominal*	*Area, circular mils*	*Weight, lb/1,000 ft*	*Resistance at 68° F* Ohms per 1,000 ft	*Resistance at 68° F* Ft/ohm
10	0.1019	10380.	31.43	0.9989	1001.0
12	0.08081	6530.	19.77	1.588	629.6
14	0.06408	4107.	12.43	2.525	396.0
16	0.05082	2583.	7.818	4.016	249.0
18	0.04030	1624.	4.917	6.385	156.5
20	0.03196	1022.	3.092	10.150	98.5

Megohm) indicates damage or deterioration. Replacement of the lead-in or loop or both may be required.[7]

4. If the detector operates satisfactorily on test loops or at other sites, obtain an inductance meter and measure the inductance of the loop. Check the specification, contact the manufacturer, or both, to insure that the detector being used will operate at the loop's inductance range.

5. If the loop operates properly under moderate weather conditions but does not operate in wet, cold, or very hot weather without retuning, the lead-in probably has excessive capacitive variation and should be replaced. If this is not practical, a self-tuning detector must be used for accurate counting.

[7]A grounded loop can work satisfactorily if the grounding is close to one side of the lead-in and if this side is connected to the ground side of the detector. If the grounded side cannot be detected with the ohmmeter, the correct side can be found by reversing the leads. This condition should be corrected.

Summary

With the information contained in this report, it is possible to design loops that easily present vehicle-caused changes in loop inductance to a detector. The well-designed traffic counting installation assures that road management decisions are based on accurate traffic data.

Effective Inductance: A key consideration in loop design. It should be in the 100 to 300 microhenry range. To compute effective inductance obtain loop inductance from table 1; calculate lead-in inductance by multiplying lead-in length in feet times 0.22 microhenries; calculate lead-in capacitance by multiplying pF/ft of your lead-in wire times its length; then refer to the effective inductance tables.

Lead-ins: A second important consideration. Limit lead-in inductance and capacitance by keeping lead-in length as short as possible. In no case should lead-in length exceed 750 feet.

Wire & Insulation: #14 or #12 AWG is recommended for loops and lead-ins; stranded copper wire is a good choice. Insulation will depend on temperature and humidity, physical characteristics of the site, and lead-in length. Type TW or THW wire with PVC insulation is adequate for short-term loops at dry sites on gravel roads and where lead-ins are short. Polyethylene-insulated type USE or UF wire is best for permanent loops or where temperatures vary widely. PE-insulated cable is recommended for long lead-ins. Belden numbers 8720 and 8718 or equivalent are good choices.

Installation: Loops should be installed at sites where traffic moves at moderate speed and passing and parking are unlikely. Avoid areas near intersections. Installation should be away from reinforcing bar in concrete highways and masses of metal. Loop sensitivity depends in part on how deep wire is buried in the road. A 1-inch-deep slot is adequate in concrete, 2 to 3 inches in asphalt, and 6 to 8 inches in gravel. Rubber splicing compound and plastic tape are adequate to seal loop-to-lead-in splices at short-term installations. At permanent sites, the additional step of sealing splices with potting compound is recommended.

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